

Experimental investigations on composite, fibre-metal and metal coupons for high velocity bird impacts

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ABSTRACT

Bird strikes on aircraft are well known and cases exist of such strikes causing extensive damage and even loss of aircraft. While aluminum has been used widely for a number of years for structural components subjected to bird strike, there is interest in using composites and fibre metal laminates in recent years. The need to use these advanced materials has been driven by their distinct advantages in terms of reduction of parts, lower weight, higher fatigue resistance and ability to keep shape when impact loads are low. Energy absorption under high velocity impact by a bird (soft body) is complex due to the highly non-linear effects that occur and the failure modes that can be associated with the materials. It was found appropriate to carry out coupon level impact studies using an airgun, through which soft bodies representing the bird in the form of gelatin cylindrical masses were fired at high speeds. Various coupons of carbon fibre composites, fibre-metal (using aluminum, glass and carbon) and metal were fabricated and tested. Data from these tests were analyzed to evaluate the energy absorption. Interesting behavior was found in the fibre-metal laminates, which showed failure mechanisms that were a combination of composite and metal, retaining integrity that would have been expected from metal coupons while having higher energy absorption.

Keywords: Bird strike impact, composite, fiber metal laminate, finite element analysis

1. INTRODUCTION

Bird strikes on aircraft are quite common and major safety issues exist as bird strikes can lead to damage to critical components leading to crashes and subsequent loss of life. Aircraft windshields, canopy, wing and tail leading edge surfaces and engines are especially vulnerable to damage due to bird strike. Bird strikes pose a complex problem to structural engineers from a design viewpoint. The impact at high velocities can result in complex non-linear behaviour in terms of material non-linearity while the bird itself could behave more like a fluid and the exact determination of the impact forces can be difficult. Important work that has led the way in understanding bird impact has been by Wilbeck and co-workers [1], where by a series of experiments, bird strike impact loads and duration of impact was estimated. Figure.1 shows a typical normalized pressure vs. time relationship with peak pressures developing for the initial part of the impact

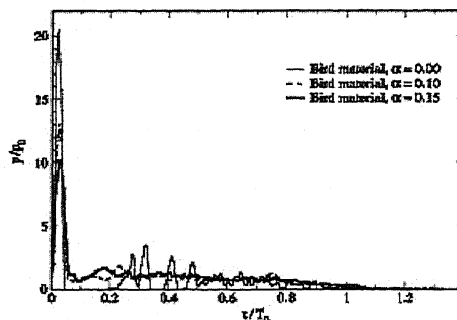


Figure 1. Normalized pressure vs. time relationship during bird strike impact

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The time duration of impact of birds was first derived by Barber [1] and was found to equal the projectile length divided by the impact velocity. During the initial impact, the particles on the front surface of the projectile are instantaneously brought to rest relative to the target face and a shock propagates into the projectile. It was conjectured in [2] that as the shock wave propagates into the projectile, it brings the material behind the shock to rest. The pressure in the shock-compressed region is initially very high and is uniform across the impact area (see Figure 2.).

After the initial phase of the impact, as the material is not radially confined, the shock is expected to emerge at the lateral free surface of the body followed by a set of release waves as shown in Figure 2. The last phase of the impact is characterized by the decay of the impact forces and the pressures exerted on the target. Given the length of the cylinder L_0 , both the total impact duration T_0 and the average force exerted on the target by the impacting body F_0 is given by:

$$T_0 = \frac{L_0}{V_i}, F_0 = \frac{MV_i}{T_0} = \frac{MV_i^2}{L_0} \quad (1)$$

Where T_0 is time duration, L_0 is length of a bird model and of an equivalent cylindrical body, M is Bird mass, V_i is Bird impact velocity and F_0 is theoretical average force exerted by a bird impacting a rigid target.

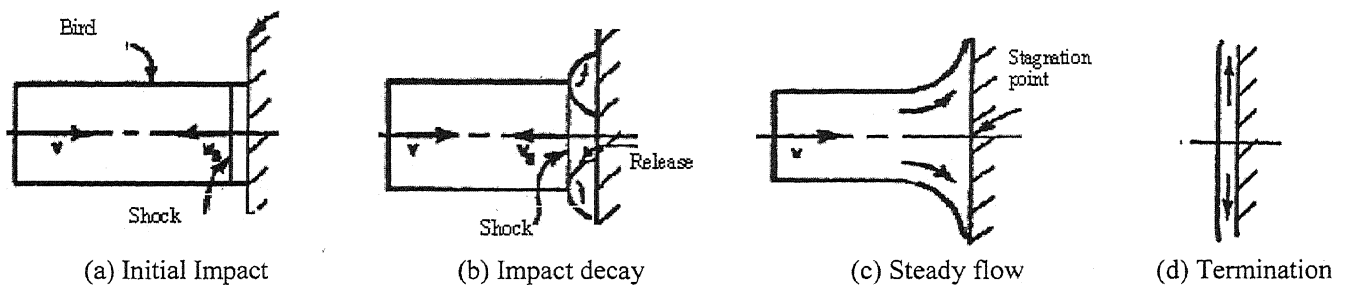


Figure 2. Different stages of bird strike impact

At the time of impact, there appear to be complex material behaviour that occurs. For example, in aluminum alloys, plasticity sets in and material failure can occur. It is possible that strain rate effects will apply to some alloys. Nonetheless, plasticity and material failure causes rupture and penetration. At the time of impact, given the kinetic energy involved, damage downstream of the leading edge (LE) of an aircraft wing is possible and needs to be studied to ensure energy dissipation occurs before damage to critical components like spars. In composites, material failure could be in the form of delamination, fibre breakage, matrix cracking etc. All of these failures, either in metals or in composites, contribute to the energy absorption, such that much of the energy is dissipated before damage to downstream components occur. Regulatory requirements like in FAR 25 applicability: 25.631 Bird strike damage. [3] tolerance is categorized through the following provision: *Damage-tolerance (discrete source) evaluation*. The airplane must be capable of successfully completing a flight during which likely structural damage occurs as a result of: (1) Impact with a 4-pound bird when the velocity of the airplane relative to the bird along the airplane's flight path is equal to V_C at sea level or $0.85 V_C$ at 8,000 feet, whichever is more critical which finally governs the design which could be based on any appropriate material type. Ubels et al [4] came out with a novel application of composites with high energy-absorbing characteristics termed as a tensor skin concept. The work involved tailoring energy absorption such that the leading edge skin fails at or below a load of 200 KN, to ensure that a load built-up is no longer possible while deflecting or absorbing the remaining kinetic energy. Thus, fibre metal laminates (FML) or tailored composite laminates have promise for energy absorption.

1.1 Energy absorption

As discussed earlier, while penetration can probably be contained, large-scale damage propagation leading to loss of integrity of the main elements needs to be avoided. Thus, the focus of the work is to study use of alternate material like composites etc. Historically, much of the work on leading edges of aircraft has been with the use of aluminum alloys that would form the part of the leading edges. Aluminum being a ductile metallic alloy has had advantages from energy absorption and penetration issues. However, in more recent years, work by Johnson and co-workers [5], etc have shown

that composites can in fact provide an efficient alternative. While modeling of composite shells for failure under impact can be complex, work shows possibilities exist for its use. The use of FML which is a combination of aluminum and glass is also known to be very effective under impact loads.

Coupons using carbon fibre and FML type of materials were used to fabricate the test coupons for understanding the behaviour of composites under impact loads. Laminates of 200mmx150mmx2mm were fabricated out of carbon fibre composites, FML and aluminum. A quasi-isotropic lay up sequence is chosen for the composite laminate. FML typically was fabricated with the intention to explore if it can be used for the LE of aircraft wings or other lifting surfaces, as it has superior characteristics in terms of shape retention (due to highly linearly elastic material like carbon/epoxy), energy absorption capability (due to the layered structure and plastic deformation), lightning protection (due to the presence of Aluminum layers), cost effectiveness (lightweight construction and simple production techniques). The glass epoxies are used as barrier between the aluminum and carbon epoxy so as to prevent the chances of galvanic corrosion. Also the presence of glass fibers helps to improve damage tolerance of the structure at high velocity impacts. FML consists of thin aluminum 2024-T3 layers, bonded together with E-glass fibres (914G-120-45%, BD) and Carbon Epoxy (914C T300-UD) system. The material is cured in an autoclave cycle with a maximum pressure of 7 bar and a curing temperature of 175°C. The Aluminum foil is of 0.2 mm, Carbon Epoxy is of 0.15mm, and Glass epoxy is of 0.12mm thick. The FML laminates have a symmetrical lay-up to avoid secondary bending effects due to unsymmetrical internal stresses. Two series of laminates were developed for these tests. The total thickness of the laminates is 2.12 mm and 1.24 mm respectively.

2. DESIGN OF THE TEST PROGRAM

A test program was designed. These included the design of the fixture, material coupons, measurement and data acquisition and high speed imaging. The test facility that is being used is located at the Gas Turbine Research Establishment (GTRE), Bangalore. The schematic layout and specifications of the facility is shown above in Figure 3. The air gun consists of a 3 cubic meter air reservoir which can be pressurized upto 31 bar (450 psi), a 12m long steel gun barrel, a solenoid operated ball valve and a breach mechanism. The projectile is propelled using a sabot, which is placed ahead of the valve using the breach. The sabot is arrested using a catcher and the projectile is released which strikes the target. Velocity of the projectile is measured using high speed photography. The strain gauges, accelerometers etc are positioned on the target and measured using a high sampling rate data acquisition system. The gelatin power is mixed with water in appropriate proportion and kept in a mould to solidify for 24 hours and the proportion is maintained to get the density of the bird equivalent to that of a real bird which is the industry accepted standard of 1.08 gm/cc. The test procedure is to place the gelatin bird in a canister (sabot) and aligned in the projectile holder of the gun. The air reservoir is pressurized to the required level. The solenoid is activated and the gun fired. High speed video of the projectile and target behaviour is recorded as well as the responses from the sensors. The test program is to develop a test fixture that can be fitted to the GTRE target mount. This structure is intended to be versatile to receive coupons as well as leading edge specimens. The fixture is also intended to provide strains which can be used to estimate the impact loads that would occur. As discussed earlier, the test program is intended to study the behaviour of composites, FML and aluminum alloys at the coupon level as well as at a feature level.

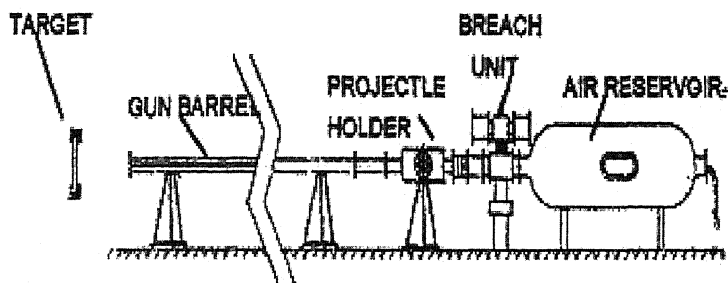
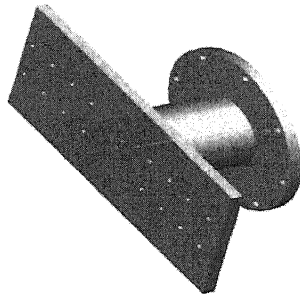


Figure 3. Schematic layout of air gun

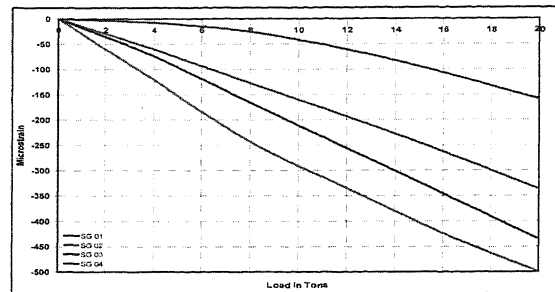
2.1 Design of fixture

A steel fixture has been designed as shown in Figure 4. that can be used to test these coupons as well as portions of the leading edge of a lifting surface of an aircraft. The fixture has sensors/strain gauges attached to be able to measure the

strains that will occur due to the impact load on the component, which is then transferred to the fixture. The fixture is mounted to the test bed and aligned to receive the bird impact. The aircraft component is mounted on a steel plate that is then bolted to the fixture. The fixture is designed to carry a load of above 30 tons without yielding. This fixture was strain gauged at the hub at four locations. The fixture was subjected to a compression test to estimate the strains obtained for a given load. The strain vs load data is shown in Figure 4. It is expected that this data would be useful during the impact tests to estimate the impacts loads on the fixture.



(a) Test fixture



(b) Load-strain calibration curve

Figure 4. Calibration test results of test fixture

2.2 Development of a coupon level energy absorption test

The coupon level energy absorption test fixture assembly (Figure 5.) was designed and fabricated and consists of the following parts: a) Fixture Plate Assembly – which has provision to hold the test laminates and the fixtures to support it to the main test rig, b) Supporting Stand Assembly – which supports the fixture from the ground, and c) Bearing Bracket Assembly – which transfers the weight of the fixture to the supporting stand and allows the free energy transfer from the impact plate to the laminates without much friction with the supporting stand assembly when subjected to impact load. The fixture plate assembly consists mainly of impact plate, base plate, outer plate and inner block plates. The impact plate takes the full impact load and transfers the energy to the laminates whose energy absorption characteristics need to be studied. The strain gauges are mounted on the impact plate, laminates and the hub to study the energy transfer

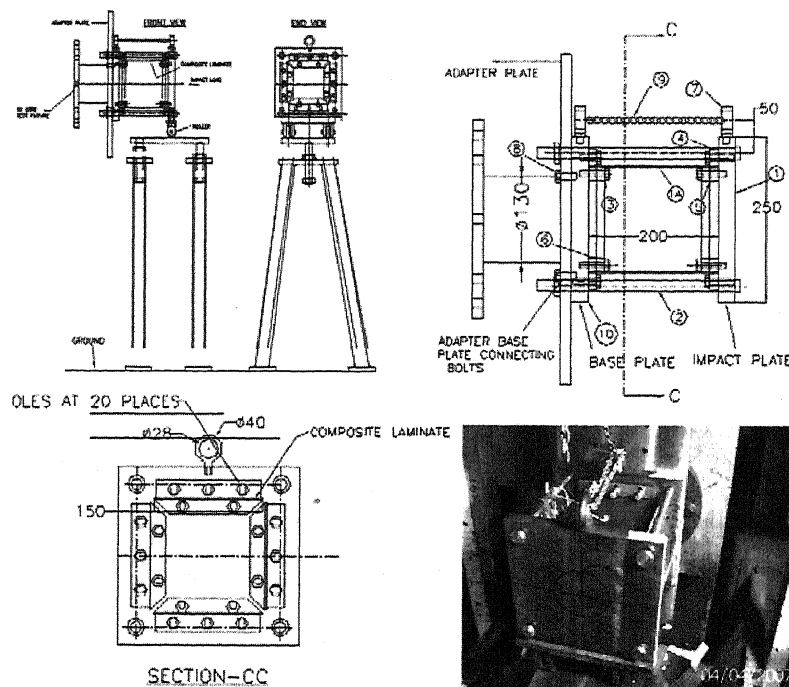


Figure 5. Diagram giving the details of Bird hit Test Fixture Assembly

due to impact loading. The 4 laminates (200 x 150 x 2t) are positioned as a rectangular box type compartment by constraining it between the outer plates and the inner block plate. The procedure being envisaged is to fire a small gelatin mass of 4 lbs that will be impacted on the impact plate at the test facility at GTRE. The strain gauge mounted on the laminates, hub, and impact plate records the energy transfer taking place during the impact. Using this fixture, specimens made out of composites, FML and aluminum were tested. Trial tests on the fixture are presently being carried out. Figure 6. shows the carbon composite specimens mounted on the test fixture prior to the firing of the airgun.

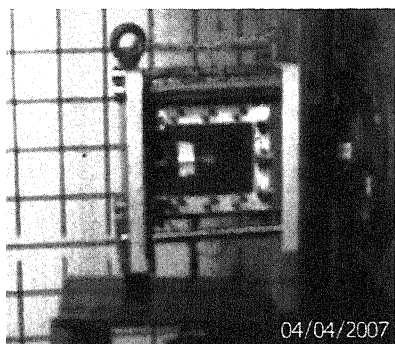


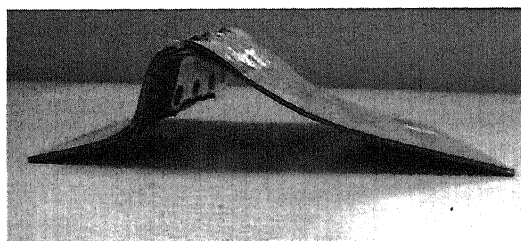
Figure 6. Specimen mounted on fixture



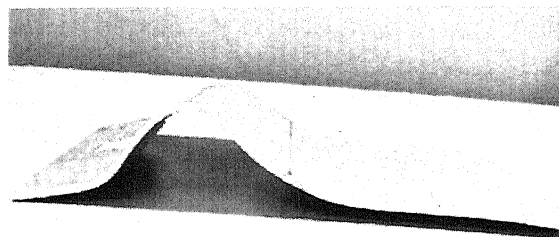
Figure 7. High speed camera image of the bird impact on an aluminum coupon

2.3 Testing

A series of tests were carried out at different velocities for the various laminates. A 4 lb gelatin (bird) mass was used. Strain data was recorded for all the gauges (16 nos) on the laminates and the fixture hub to understand the failure strains and the energy absorption which could be estimated by comparing the hub strains. Figure 7 shows an impact recorded using a high speed camera for an aluminum coupon. Figure 8a shows the failure of the FML specimen and Figure 8b shows the failure of an aluminum specimen



(a) FML



(b) Aluminum

Figure 8. Post Impact photograph

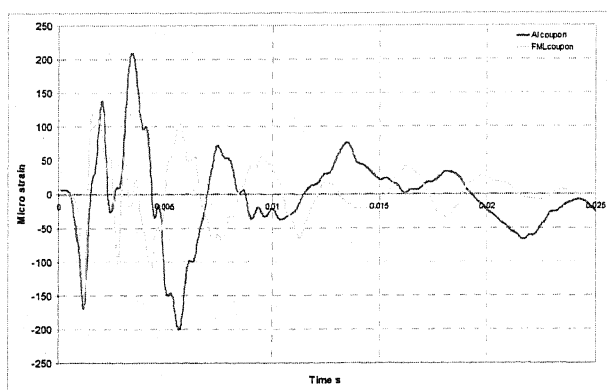


Figure 9. Time histories of hub strain measured from Al / FML test coupons subjected to 4-lb bird strike

The typical failure patterns indicate that carbon laminates while absorbing energy do not retain integrity and given the high strength and brittle nature fail and show fibre breakage, delamination and cracking. In comparison, FML retains integrity and fails like the aluminum coupons, but shows delamination, cracking and aluminum layers fail. All these sub events lead to energy absorption. The Aluminum coupons show plastic deformation but also retain elastic energy which tends to be released at the end the impact. From the strain data on the hub (see Figure 9), it appears that the Aluminum coupons show lesser energy absorption than the FML components.

2.4 Simulation studies

Simulation studies were carried out for the aluminum (see Figure 10.) and FML coupons based on material properties that were acquired through characterization tests. The studies were conducted using explicit FE codes (PAMCRASH). It appears that good correlations in terms of strains and the failure modes were obtained. More details on the simulation-test correlations will be reported separately due to the need for brevity. Figure 11. shows the failure mode from the simulation.

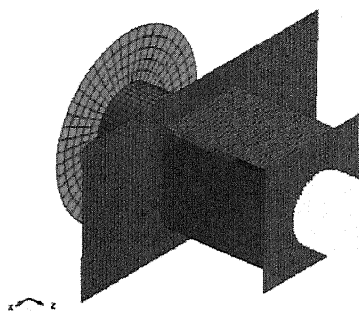


Figure 10. FE-Model of the test setup with the specimen and the SPH bird Model

PAM-SOLID Simulation

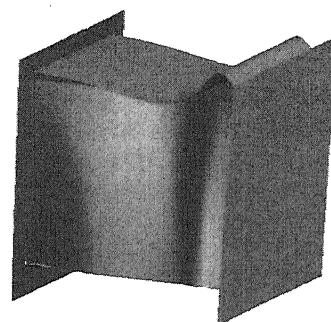


Figure 11. Deformation shape of the Aluminum coupon subjected to bird impact through FE-Simulation

CONCLUSIONS

Energy absorption capabilities of various materials under high speed impact of soft bodies (bird strike): aluminum, fibre metal laminates and composite laminates were examined. The GTRE air gun was used to carry out the tests. A specially designed fixture that would transmit compressive loads was fabricated. The coupons were extensively strain gauged. High speed videography was used to record the impact. Based on the test results, it was found that FML laminates had failure modes similar to aluminum and showed the higher energy absorption occurred compared to aluminum.

ACKNOWLEDGMENTS

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REFERENCES

1. J. P. Barber, H. R. Taylor and J. S. Wilbeck, Characterization of Bird Impacts on a Rigid Plate: Part 1. Dayton University, National Technical Information Service U.S Department of Commerce, January 1975
2. A. Airolidi, B. Cacchione, Modeling of impact forces and pressures in Lagrangian bird analysis, *International Journal of Impact Engineering*, 32(10), pp. 1651-1677, 2006
3. Federal Aviation Requirements, FAR-25, §25.631 *Bird Strike Damage*, 1993
4. L.C. Ubels, A.F. Johnson, J.P. Gallard and M. Sunaric, Design and Testing of a Composite Bird Strike Resistant Leading Edge, *SAMPE Europe Conference Exhibition*, National Aerospace Laboratory, 2003.
5. A.F. Johnson, M. Holzapfel, Modeling soft body impact forces on composite structures, *Composite Structures*, 61, pp. 103 – 113, 2003.